MINERAL COMPOSITION OF GLUTEN, STARCH, AND WATER-SOLUBLES FRACTIONS OF WHEAT FLOUR AND ITS RELATIONSHIP TO FLOUR QUALITY

by

ROBERT KNEBLER BEQUETTE

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INTRODUCTION AND REVIEW OF LITERATURE

Mineral composition of wheat and flour is known to vary with environment and heredity. Environmental factors include weather, available nutrients in the soil and the physical condition of the soil. Beeson (5) and Bailey (3) have reviewed the extensive early literature on the mineral composition of wheat and flour. Many of these early analyses were carried out on samples of unknown origin and frequently information on soil, climatic factors, variety, and baking quality were lacking. Most results indicated the total ash and composition of the ash varied greatly.

Uptake of available nutrients by the wheat plant is affected by variety and soil moisture as well as the relative ratios of the elements in the soil (5). Greaves and Carter (17) found that the total ash in the grain increased progressively as the amount of irrigation water increased. Most of the increase resulted from additional phosphorus, potassium, calcium, and magnesium absorbed by the plants. In a later paper, Greaves, et. al. (16) reported that spring wheat contained greater percentages of total ash, calcium, potassium, iron, phosphorus, and sulfur than winter wheat grown on the same soil. This was assumed to be due to genetic differences between the two classes of wheats. Additions of green manure caused a significant increase in total ash, calcium, and phosphorus presumably because of the increased availability of these elements. No data on baking quality were reported.

Schrenk and King (36) reported that ash and mineral content of three wheat varieties grown for three years at 13 locations within the state of Kansas varied appreciably and were correlated, in general, with available nutrients in the soil. The availability of nutrients depended on the rain-

fall since high annual rainfall leached available nutrients from the soil. Areas producing wheat with high mineral content also produced wheat with high protein. Mineral content was influenced greatly by location, but only slightly by variety. Areas producing high mineral content did so consistently, indicating that differences due to rainfall and other environmental factors during the three-year period did not affect mineral content significantly. The increased ash content of Western Kansas wheats was not due to increases in any one element, but was the result of combined increases in each of the major constituents of the ash. The changes in minor element composition showed no definite trend with respect to location.

In a continuation of this work, Schrenk (35) studied the effects of calcium, magnesium, and phosphorus applications on the composition of grain produced in Southeastern Kansas. The percentage of protein decreased due to fertilizer treatment, while the mineral content of the grain increased. This suggests that when non-nitrogenous fertilizers were applied at these locations nitrogen content of the soil became a limiting factor. The most noticeable effect of soil treatment was the increase in phosphorus content of the grain. Magnesium decreased when only calcium and phosphorus were applied to the soil. When these two nutrients were supplemented with magnesium, magnesium also increased in the grain.

Information accumulated at the Hard Winter Wheat Quality Laboratory (Finney, et. al., 12) and representing many varieties grown throughout the Great Plains, indicates that total ash is controlled by two factors. These are variety and environment, the most important of which is environment. Variety plays a minor role in determining mineral content of whole wheat under field conditions. Conditions that favor accumulation of protein in

the kernel generally favor accumulation of minerals.

Significant differences in the mineral composition of portions of the whole wheat kernel also have been measured. Morris, et. al. (27), employing a microdissection technique to separate whole wheat kernels into fractions, found evidence of an increasing gradient in ash and protein content extending outward from the center of the endosperm. Comparison of the ash and protein contents of the dissected fractions with those of Buhler flour mill streams of Thorne soft wheat showed that the dissected fraction with the lowest ash was identical with the flour stream with the lowest ash. The flour streams with the highest ash were slightly lower in ash than the dissected fractions with the highest ash. It is known generally that cations influence dough behavior and exert a modifying effect on the flour proteins (13, 25). Several methods of determining flour quality based on the measurement of physico-chemical properties of dispersed flour proteins have been shown to be affected by electrolytes present in wheat ash (Miller and Johnson, 25). Increasing the salt concentration of doughs prepared for testing in the Brabender Extensograph increases both the extensibility and resistance to extension of doughs. Weak and strong flours respond differently to added salt (Fisher, et. al., 13).

Water containing a medium degree of hardness is considered most suitable for baking purposes as some of the mineral salts have a strengthening effect on the gluten. Soft waters are objectionable in baking because they tend to yield a soft, sticky dough (Fyler, 33). Patented preparations generally are used to bring commercial doughs to a maximum ionic strength, regulated by the solubility of calcium sulfate.

Sullivan and Near (39) analyzed the ash of 20 wheat samples of widely

different character and origin and reported that magnesium content was related directly to the strength of wheats as determined by protein percentage and gluten quality. The gluten quality score was based on physical properties of dough and washed gluten. This subjective method of evaluating gluten quality leaves much to be desired.

Davidson and Shollenberger (6) studied effects on flour baking quality of sodium nitrate applied at different stages during growth of the wheat plant. Flour protein, ash, and absorption, loaf volume, and total loaf score increased with increases in length of time from seeding until sodium nitrate was applied. The highest flour protein, ash, and absorption, and highest quality loaves resulted from application of sodium nitrate at heading time.

Gericke (14, 15) grew wheat in hydroponic solutions and studied the effects on bread scores of nitrate and chloride salts supplied during the later period of plant growth. The quality of flour from wheat grown in cultures where nitrogen was supplied in the form of ammonia was decidely inferior to that milled from wheat grown in cultures supplied with nitrogen in the nitrate form. In both series, the use of calcium nitrate or chloride resulted in higher bread scores than did the similar salts of potassium, sodium, and magnesium. The use of ammonium nitrate resulted in the poorest loaf produced from wheat grown in solutions containing different nitrate salts. Some question of the validity of these results might be raised due to the inadequacy of the baking tests used by Gericke. Although each sample was baked by both basic and stimulated (diastased) methods, in several cases, quality rankings varied between baking methods. Recently developed bread-making methods (Finney, 9) are much better able to measure the breadmaking potential of flours.

McCalla and Woodford (23) employed the liquid culture technique of Gericke and reported that limiting the supply of potassium to wheat plants had an adverse effect on the quality of grain as determined by gluten and baking tests.

Separation of flour doughs or flour-water suspensions into their component complexes and reconstitution of these complexes to produce "synthetic" doughs has yielded considerable information on factors determining flour quality. Unfortunately, methods of making these separations have varied and some of the data obtained have been contradictory. The gluten complex, however, has been shown to be the most important substance in the flour. It is responsible for the elastic and cohesive properties of a flour dough and forms the three-dimensional network which is responsible for the characteristic porous structure of leavened bread. Pence, et. al. (30) and Sullivan (38) recently reviewed the literature on the role of wheat flour protein in baking.

Early workers separated gluten into fractions based on solubility in various solvents in an attempt to determine factors responsible for the unusual properties of gluten and the reasons for variation in properties of gluten obtained from different flours. The most important conclusion drawn from this work was that gluten consists of many components varying progressively in solubility and other physical properties (Miller and Johnson, 25).

Swanson (40) discussed the influence of electrolytes on the physical properties of doughs and on flour proteins. Doughs are influenced directly by the kind and amount of salt present, and indirectly by their effect on pH. Increase in viscosity of a dough in the presence of a salt was attributed to the appropriation of water by the salt molecules or ions. Decrease in viscosity would be caused by a dispersing effect on the gluten.

Few analyses of gluten obtained from flours of widely different dough

characteristics and baking quality have shown significant differences in the amounts or kinds of amino acids. Miller, et. al. (26) studied the "microbiologically apparent" lysine, glutamic acid, cystine, and methionine content of whole wheats and found a relationship between mixing time and percent of both cystine and methionine as influenced by environment. No differences due to variety were observed. Flour from wheat samples high in cystine required the longest mixing for optimum dough development. Wöstmann (42) reported a positive correlation between flour strength, as reflected by surface area of extensograms, the cystine content of flour proteins, and total cystine content of the flour. Cystine was determined polarographically.

Present evidence indicates that variations in gluten properties, in part, are due to modifying influences exerted by the other dough complexes, mainly those materials extractable in water. Pence, et. al. (28, 29, 31) made detailed studies of effects of water-soluble flour components on baking behavior. They found that soluble pentosans had little effect on the baking performance of doughs reconstituted without the use of the water-soluble fraction of the flour, but the handling properties of the doughs were modified distinctly. These pentosans corrected to a large degree the softness, wet surface, and lack of normal stickiness shown in doughs reconstituted with only gluten and starch. Improvements in volume, grain, and texture, however, were small.

The soluble components of the flours were required for maximum performance of all glutens except that from a durum wheat, and appeared to be capable of affecting flour behavior to such an extent that differences or similarities in gluten characteristics were obscured. The pentosans of the crude albumin fraction (non-dialyzable portion of the water-solubles) were responsible for

the shortened mixing time of doughs containing this fraction. The amounts of soluble proteins were found to increase directly with total flour protein, but the relationship became inverse when they were expressed as percentages of total protein. The ratios of albumins to globulins contained by flours were correlated with protein quality beyond the one percent level of significance. The authors postulated that albumin components act in a beneficial manner in bread doughs, whereas, globulins act in a deleterious manner. The resultant effect of the two proteins is reflected by the ratio of their amounts.

Mattern and Sandstedt (22) reported that the principal factor responsible for determining the mixing requirement of wheat flour is water-soluble. The mixing time of a flour was lengthened by removal of the water-soluble fraction. Reincorporation of the solubles reversed this effect. The mixing requirement of a flour also was extended by incorporating water extracted flour with a normal flour.

Starch has been shown to exert some effect on dough properties and loaf quality although these effects are rather small compared to those reported for the gluten and water-soluble fractions. According to Sandstedt, et. al. (34) the "amylodextrin" or "tailings starch" fraction of flour is a factor in absorption and exerts its influence on the handling characteristics of flour doughs. This material was associated with stickiness of doughs and with tenderness of crumb in the baked product. Harris and Sibbit (18, 19) found marked differences in the comparative baking qualities of starch prepared from different wheat varieties. Synthetic flours were produced by adding these starches to a constant gluten substrate at three protein levels.

Present evidence provided by Mattern and Sandstedt (22) leads to doubt

of the validity of early reports concerning the positive effects of starch in determining dough characteristics and bread quality. Sandstedt, et. al. (34) and Harris and Sibbit (19) separated the gluten and starch from a dough mixed to optimum development and discarded the water-solubles.

In more recent work, (8, 22, 37, 43) the flour complexes have been separated by methods designed to keep dough development at a minimum. Under these conditions, the water-solubles are necessary in reconstituting a "synthetic dough" which will result in bread of quality equal to that from a normal flour.

Little is known about the relative distribution of the minerals in the complexes separated from hydrated flours and their relationship to the technological behavior of flour. El Gindy, et. al. (7) studied the influence of variety, fertilizer treatment, and soil on the protein content and mineral composition of wheat, flour, and flour fractions (gluten, starch, and water-solubles). Milling behavior and flour yield were not affected noticeably by soil differences or fertilizer treatments. Total wheat ash was affected by fertilizer treatments and varied among varieties. The percentage of specific elements in the ashes of the wheat and the flour fractions varied greatly among varieties for some elements. There was no consistent relationship among varieties and elemental composition compared as absolute amounts or as percentages of the ash. The authors concluded that a complex hereditary background probably influenced composition of the ash. No information on the baking characteristics of these flours was presented.

The literature suggests that flour and gluten quality are controlled by a factor or factors which are subtile in nature. One of these factors about which there is little information is the mineral composition of flour and its

component parts and the relationship between mineral composition and baking characteristics of the flours. The object of this study was to separate hydrated flour into gluten, starch, and water-soluble complexes and to correlated the results of mineral analyses of these fractions with baking quality data.

MATERIALS AND METHODS

The flours used in this study consisted of 40 samples representing five pure varieties of hard red winter wheat grown at eight locations in Kansas in 1956. All wheat samples were milled to a straight-grade flour on an Allis mill (Johnson, et. al., 20). Data pertaining to these samples are presented in Table 1.

Moisture, ash, and protein were determined according to the methods of the A. A. C. C. (1). Baking absorption was based on farinograph data obtained using the constant flour weight method.

The straight-dough baking procedure was patterned after that described by Finney (9). It was the same as that used by Miller, et. al. (24).

Mixograms were made according to the procedure of Johnson, et. al. (21). They were measured using the method described by Swanson and Johnson (41).

The flour complexes or fractions were prepared by a modification of the method developed by Finney (8). Details of this procedure are given in the Appendix. The samples were ashed according to the procedure given in the Appendix.

The mineral analyses were performed using both chemical and flame photometric technics. Total phosphorus was determined by the reduced molybdate colorimetric procedure of Fons, et. al. (32) (See Appendix). Iron

was determined according to the A.O.A.C. method (2) using alpha, alpha-dipyridyl as the complexing agent. Sodium, calcium, potassium, manganese, and magnesium were determined with a Beckman D. U. spectrophotometer equipped with flame photometry attachment and atomizer burner assembly (4). Details of the flame analysis procedure are given in the Appendix.

RESULTS AND DISCUSSION

Baking Quality

The protein and loaf volume data presented in Table 1 indicate that many of these flour samples contain protein of abnormal baking quality. An outstanding example of this is the comparison between protein content and loaf volumes of the samples grown at Hays and Belleville. The Hays samples averaged 16 percent protein and produced bread with an average loaf volume of 930 c.c. The Belleville samples averaged 12.8 percent protein and produced loaves averaging 943 c.c. The protein and loaf volume data of samples grown at Manhattan, Garden City, and Canton indicated that these samples also contained protein of inferior baking quality, while the samples from Colby, Mound Valley, Thayer, and Belleville were of much higher baking quality. The normally expected differences in protein quality among varieties were altered considerably by effects of environment during the growth of the samples studied.

The summer of 1956 was extremely hot and dry, and it is assumed that these conditions caused the observed differences in flour quality. Finney and Meyer (11) have shown that subnormal loaf volume, water absorption, and mixing properties were consistently associated with high temperatures

Table 1. Summary of analytical, physical dough testing, and baking data for the flour samples.

Station	Bison	Pawnee	Ponca	Conchos	RedChief	Ave.	Bison	Pawnee	Ponca	Conchos	RedChief	Ave.
	Flour Protein (14% M.B.)						Flour Ash (14% M.B.)					
Manhattan	17.3	17.4	17.3	16.5	17.1	17.1	0.41	0.42	0.43	0.41	0.44	0.42
Hays	17.2	15.5	16.3	15.6	15.3	16.0	0.48	0.43	0.49	0.43	0.45	0.46
Colby	14.8	14.4	14.3	13.7	13.8	14.2	0.44	0.43	0.47	0.44	0.44	0.44
Garden City	15.2	14.9	14.9	14.7	14.1	14.8	0.42	0.42	0.47	0.41	0.44	0.43
Mound Valley	11.3	12.1	10.7	11.0	10.6	11.1	0.39	0.39	0.43	0.39	0.42	0.40
Thayer	12.7	13.1	12.7	12.5	13.1	12.8	0.40	0.42	0.41	0.37	0.37	0.39
Belleville	13.1	12.9	12.9	12.2	13.1	12.8	0.39	0.39	0.39	0.36	0.38	0.38
Canton	15.7	17.0	15.5	16.1	15.2	15.9	0.44	0.46	0.48	0.44	0.48	0.46
Average	14.7	14.7	14.3	14.0	14.0	14.3	0.42	0.42	0.45	0.41	0.43	0.42
	Mixograph Mixing Time (minutes)						Farinograph Mixing Time (minutes)					
Manhattan	3.50	2.75	2.75	4.50	3.50	3.40	9.00	9.25	9.25	11.50	8.00	9.40
Hays	3.50	2.75	3.00	2.75	2.75	2.95	8.75	5.25	6.75	8.00	4.75	6.70
Colby	4.50	2.75	4.00	3.00	3.00	3.45	11.00	6.00	7.50	6.25	5.50	7.25
Garden City	3.00	1.75	2.50	2.25	3.00	2.50	7.50	5.00	5.50	7.75	6.25	6.40
Mound Valley	4.25	1.75	3.75	2.75	2.75	3.05	8.00	4.50	5.00	5.25	5.00	5.55
Thayer	4.00	2.40	4.00	3.00	2.50	3.18	7.75	5.50	8.50	6.25	5.00	6.60
Belleville	5.00	2.87	3.50	3.00	3.00	3.47	11.00	5.75	8.00	7.50	6.00	7.65
Canton	4.25	2.75	6.00	4.00	2.75	3.95	10.50	10.00	12.00	13.50	7.50	10.70
Average	4.00	2.47	3.69	3.16	2.91	3.24	9.19	6.41	7.80	8.25	6.00	7.53
	Loaf Volume (c.c.)						Gluten Quality Score					
Manhattan	945	1050	1040	1020	970	1005	45	52	52	54	47	50
Hays	987	980	965	910	808	930	48	55	50	48	41	48
Colby	942	992	952	957	787	966	55	64	60	64	44	57
Garden City	880	867	835	887	837	861	48	48	45	51	48	48
Mound Valley	925	895	840	840	782	856	83	70	78	73	69	75
Thayer	945	947	882	875	847	899	72	68	63	63	55	64
Belleville	912	957	970	950	925	943	58	71	72	77	65	69
Canton	1022	932	985	950	922	962	58	45	56	50	51	52
Average	945	953	934	924	860	928	58	59	60	60	52	58

(above 90°F.) during the last 15 days of ripening. High temperatures did not always impair protein quality, however, because of mitigating physical conditions in the soil or relatively high humidity. Varieties with long mixing times were found to be more tolerant to the detrimental effects of high temperature during fruiting than were varieties with short mixing requirements.

It is commonly accepted that the protein content of wheat flours is the principle factor determining their bread-baking properties. Since the protein content of the samples vary from 10.6 to 17.4, a direct comparison of the baking performance of more than a few of the samples was not possible. For this reason, a simple numerical protein quality value was required. Finney (8) has shown that the relation between protein content and loaf volume is substantially linear for each variety between the limits of 8 and 20 percent protein for samples grown under normal conditions, and provided an adequate baking formula is used.

Since regression of loaf volume on protein content varies with variety, the loaf volume vs. protein content regression lines for varieties represent differences in protein quality. Using this system of variety regression lines, Finney and Barmore (10) developed a method of correcting experimentally obtained loaf volumes to a constant protein basis. Pence, et. al. (31) used the coefficient of regression of loaf volume on flour protein as a measure of the baking quality of flour proteins.

In the present work, the graph (10) developed by Finney for correcting loaf volumes to a constant protein basis was used to assign a baking quality score to each sample. The slope of the line on which the point representing the experimentally determined flour protein and loaf value coincided was

assigned as the gluten quality score of the sample. Protein, loaf volume, and gluten quality score data in Table 1 indicate that this method ranked the samples in the proper order of flour quality based on a consideration of flour protein and loaf volume.

Composition of the Flour Fractions

Data for protein, total ash, and elemental composition of the flour fractions are presented in Tables 2 to 10. Results of analyses of variance of ash and elemental composition of the flour fractions as related to location and variety are presented in Table 11. Environment was the predominant factor, while variety played a secondary role in determining the elemental composition of the flour fractions. The differences in elemental composition related to environment and variety may be observed from the average values for the fractions recorded in Tables 2 through 10.

The flour protein was distributed among the complexes as follows: water-solubles 7 percent, gluten 83 percent, and starch 10 percent. Protein content of the water-solubles varied from 13.1 to 25.0 and averaged 18.5 percent. Protein in the starch ranged from 1.0 to 3.4 and averaged 1.7 percent. Protein in the gluten ranged from 54.1 to 69.1 and averaged 60.4 percent. This value for protein content of the gluten is lower than that reported by Sullivan (38) who listed the following average gluten composition: protein, 73 percent; lipides, 7.1 percent; starch, 5.1 percent; and ash, 0.60 percent. These values, however, were based on a procedure in which buffer solutions were used to wash glutens from doughs mixed to optimum development and are not directly comparable to this work.

The water-solubles contained 40, the gluten 20, and the starch 40 percent

Table 2. Summary of protein analyses for water-solubles, gluten, and starch fractions of the flours.

Station	Grams protein in the fraction from 100 grams of flour (11% M.B.)						Protein as percent of the flour fraction (11% M.B.)					
	Bison	Pawnee	Ponca	Concho	RedChief	Ave.	Bison	Pawnee	Ponca	Concho	RedChief	Ave.
Water-Solubles												
Manhattan	0.89	0.90	0.90	0.75	0.67	0.82	25.0	23.2	20.3	19.6	17.2	21.1
Hays	0.86	0.85	0.86	0.77	0.65	0.80	23.1	17.2	19.7	18.0	14.7	18.5
Colby	0.83	0.77	0.77	0.79	0.61	0.75	21.6	14.7	18.1	18.9	15.0	18.5
Garden City	0.92	0.96	0.96	0.87	0.76	0.89	19.9	21.6	20.9	20.4	16.8	19.9
Mound Valley	0.84	0.90	0.82	0.83	0.91	0.86	18.6	18.6	16.6	17.2	13.7	16.9
Thayer	0.77	0.84	0.83	0.85	0.68	0.79	15.7	18.4	18.7	19.7	14.1	17.3
Belleville	0.76	0.79	0.78	0.78	0.70	0.76	16.9	18.1	17.6	16.9	13.1	16.5
Canton	0.86	0.85	0.84	0.81	0.68	0.81	21.0	20.3	18.4	19.0	14.9	18.9
Average	0.84	0.86	0.84	0.81	0.71	0.81	20.3	19.5	18.8	18.7	14.9	18.5
Gluten												
Manhattan	14.13	11.95	12.01	11.69	11.74	12.30	65.9	58.6	55.6	58.8	55.6	58.9
Hays	9.72	9.97	12.18	10.19	10.35	10.54	65.5	63.6	59.8	60.7	59.1	61.7
Colby	9.45	9.27	9.28	7.28	9.45	8.95	69.1	61.0	57.7	60.3	58.2	61.3
Garden City	8.96	9.16	9.71	9.18	9.13	9.11	65.5	56.3	56.6	60.0	57.1	59.1
Mound Valley	6.13	6.85	6.07	5.13	6.55	6.21	67.5	61.4	58.1	62.8	57.0	61.4
Thayer	7.54	8.04	7.94	7.15	8.66	7.87	63.9	58.7	58.7	59.8	55.4	59.3
Belleville	8.14	8.03	7.24	6.78	8.45	7.73	66.9	64.1	63.3	66.0	62.3	64.5
Canton	10.53	11.64	10.40	10.92	10.54	10.81	61.2	54.1	56.3	55.7	55.6	56.6
Average	9.32	9.40	9.35	8.65	9.40	9.23	65.7	59.7	58.3	60.5	57.5	60.4
Starch												
Manhattan	0.72	0.74	0.68	0.72	0.63	0.70	1.2	1.3	1.2	1.2	1.0	1.2
Hays	0.82	1.20	1.17	1.11	0.74	1.01	1.4	2.0	2.0	1.8	1.1	1.7
Colby	1.07	1.19	1.16	2.31	0.67	1.28	1.7	1.9	1.9	3.4	1.0	2.0
Garden City	0.85	0.90	1.11	0.88	0.88	0.92	1.4	1.5	1.8	1.4	1.3	1.5
Mound Valley	1.11	1.64	1.39	2.11	1.50	1.61	1.7	2.4	2.0	3.3	2.0	2.3
Thayer	1.78	1.17	0.96	1.09	0.68	1.14	2.6	1.8	1.5	1.6	1.0	1.7
Belleville	1.31	1.58	1.72	1.96	0.98	1.51	2.0	2.4	2.6	2.7	1.4	2.2
Canton	0.73	0.85	0.91	1.01	0.64	0.83	1.2	1.5	1.5	1.6	1.0	1.4
Average	1.05	1.16	1.14	1.44	0.84	1.12	1.7	1.8	1.8	2.1	1.2	1.7

Table 3. Distribution of ash in the water-solubles, gluten, and starch fractions of the flours.

Station	Milligrams of ash in the fractions from 100 grams of flour (14% M.B.)						Milligrams of ash per gram of fraction (14% M.B.)					
	Bison	Pawnee	Ponca	Concho	Kenchief	Ave.	Bison	Pawnee	Ponca	Concho	Kenchief	Ave.
Water-Solubles												
Manhattan	136	129	130	119	124	127	38.1	33.2	29.4	31.2	31.8	32.8
Hays	139	119	132	118	112	124	37.3	24.1	30.0	27.6	25.2	28.8
Colby	136	119	142	133	125	131	35.4	28.7	33.2	31.8	30.8	32.0
Garden City	129	122	145	126	135	131	28.0	27.4	31.5	29.8	30.0	29.3
Mound Valley	143	136	157	146	153	147	31.6	28.0	31.8	30.1	23.2	29.0
Thayer	141	121	127	126	115	128	28.6	26.1	30.7	29.3	23.8	27.7
Belleville	127	112	126	118	115	120	28.1	25.6	28.6	25.4	21.6	25.9
Canton	128	124	139	128	124	129	32.5	29.5	30.5	30.0	27.2	30.0
Average	135	122	138	127	125	130	32.5	27.8	30.7	29.4	26.7	29.4
Gluten												
Manhattan	74	80	82	79	96	82	3.4	3.9	3.8	4.0	4.5	3.9
Hays	57	58	101	74	95	77	3.9	3.7	5.0	4.3	5.4	4.4
Colby	51	67	76	53	83	66	3.7	4.4	4.7	4.4	5.1	4.5
Garden City	61	77	84	70	78	74	4.5	4.6	4.9	4.4	4.8	4.6
Mound Valley	30	44	42	33	44	39	3.3	3.9	4.1	3.8	3.8	3.8
Thayer	41	50	52	42	62	49	3.5	3.6	3.9	3.5	3.9	3.7
Belleville	41	51	42	36	52	45	3.4	4.1	3.6	3.6	3.9	3.7
Canton	68	100	87	83	107	89	4.0	4.6	4.7	4.2	5.7	4.6
Average	53	66	71	59	77	65	3.7	4.1	4.3	4.0	4.6	4.2
Starch												
Manhattan	130	122	126	119	121	124	2.2	2.2	2.2	2.0	1.9	2.1
Hays	133	123	139	131	117	134	2.2	2.0	2.4	2.1	2.2	2.2
Colby	133	134	137	146	127	136	2.1	2.2	2.2	2.2	1.9	2.1
Garden City	125	122	129	123	128	125	2.0	2.0	2.1	2.0	1.9	2.0
Mound Valley	129	130	111	94	130	119	2.0	1.9	1.6	1.3	1.7	1.1
Thayer	135	124	124	121	119	124	2.0	1.9	1.9	1.8	1.8	1.9
Belleville	131	131	123	121	125	126	2.0	2.0	1.8	1.7	1.8	1.8
Canton	127	129	135	132	137	132	2.1	2.3	2.2	2.0	2.1	2.2
Average	130	127	128	123	129	128	2.1	2.1	2.1	1.9	1.9	2.0

Table 4. Distribution of phosphorus in the water-solubles, gluten, and starch fractions.

Station	Milligrams of phosphorus in the fraction from 100 grams of flour (14% M. B.)						Phosphorus as percentage of the ash					
	Eison	Pawnee	Ponca	Concho	RedChief	Ave.	Eison	Pawnee	Ponca	Concho	RedChief	Ave.
Water-Solubles												
Manhattan	13.10	12.90	10.86	8.64	12.40	11.58	9.65	9.98	8.35	7.26	10.02	9.05
Hays	15.65	16.45	15.54	11.88	14.11	14.73	11.27	13.79	11.82	10.09	12.64	11.92
Colby	12.66	12.80	12.90	12.18	12.29	12.57	9.28	10.78	9.11	9.15	9.81	9.63
Garden City	14.26	14.22	15.58	10.88	16.04	14.20	11.06	11.66	10.76	8.60	11.90	10.80
Mound Valley	11.70	11.09	13.44	9.68	14.49	12.08	8.18	8.16	8.57	6.64	9.45	8.20
Thayer	13.60	12.80	11.80	8.93	13.47	12.12	9.63	10.34	8.61	7.10	11.72	9.48
Belleville	11.42	12.74	10.83	8.44	13.45	11.38	9.01	11.39	8.56	7.19	11.73	9.58
Canton	15.15	15.35	14.41	11.68	14.78	14.27	11.86	12.37	10.36	9.10	11.94	11.13
Average	13.44	13.55	13.17	10.29	13.88	12.87	10.00	11.06	9.52	8.14	11.15	9.97
Gluten												
Manhattan	33.28	28.24	27.82	28.04	34.67	30.41	45.12	35.49	33.89	35.52	36.33	37.27
Hays	26.16	27.48	41.04	30.08	37.10	32.37	45.56	47.10	40.48	40.49	39.22	42.57
Colby	24.90	25.66	23.66	19.90	29.12	25.65	49.06	38.02	37.92	37.46	35.18	39.53
Garden City	24.90	29.14	32.78	27.46	31.28	29.11	40.72	37.86	39.14	39.41	39.85	39.40
Mound Valley	13.98	18.34	16.26	11.53	17.76	15.58	46.81	41.81	38.40	35.10	40.16	40.46
Thayer	18.13	19.96	20.62	17.78	23.00	19.89	44.26	40.36	39.51	41.98	37.40	40.70
Belleville	16.79	19.54	16.50	13.83	20.56	17.44	40.38	38.26	39.72	37.78	39.28	39.08
Canton	30.41	36.58	33.98	30.04	39.95	34.19	44.76	36.56	38.94	36.16	37.23	38.73
Average	23.57	25.61	27.21	22.33	29.18	25.58	44.58	39.43	38.50	37.99	38.08	39.72
Starch												
Manhattan	30.80	28.38	24.90	27.52	30.85	28.49	23.72	23.24	19.73	23.05	25.44	23.04
Hays	34.87	33.63	35.32	34.57	41.23	35.92	26.31	27.37	25.18	26.42	28.11	26.74
Colby	35.06	27.02	37.52	37.92	36.80	34.87	26.37	20.09	27.38	25.88	28.85	25.71
Garden City	31.88	33.92	36.19	31.93	36.70	34.14	25.66	27.92	28.05	25.95	28.72	27.26
Mound Valley	26.47	32.36	33.60	34.12	32.23	32.15	22.13	24.82	30.25	36.48	24.66	27.67
Thayer	28.86	29.17	31.52	31.44	30.94	30.38	21.42	23.73	25.52	25.99	25.91	24.51
Belleville	25.52	30.82	30.32	28.37	30.24	29.06	19.50	23.19	24.70	23.19	24.27	23.09
Canton	34.90	34.57	34.32	35.59	33.80	34.64	27.43	26.84	25.38	26.99	24.63	26.25
Average	31.30	31.24	32.96	32.68	34.10	32.46	24.07	24.69	25.81	26.78	26.32	25.53

Table 5. Distribution of iron in the water-solubles, gluten, and starch fractions.

Station	Micrograms of iron in the fractions from 100 grams of flour (14% M. B.)						Iron as percentage of the ash					
	Bison	Pawnee	Ponca	Concho	RedChief	Ave.	Bison	Pawnee	Ponca	Concho	RedChief	Ave.
Water-Solubles												
Manhattan	4	54	51	35	64	42	0.01	0.04	0.04	0.03	0.05	0.03
Hays	103	79	50	87	51	74	0.07	0.07	0.04	0.07	0.05	0.06
Colby	66	66	49	57	102	68	0.05	0.06	0.03	0.04	0.08	0.05
Garden City	75	74	86	40	72	69	0.06	0.06	0.06	0.03	0.05	0.05
Mound Valley	62	78	56	77	76	70	0.04	0.06	0.04	0.05	0.05	0.05
Thayer	96	48	20	40	33	47	0.07	0.04	0.02	0.03	0.03	0.04
Belleville	28	40	10	83	49	42	0.02	0.04	0.01	0.07	0.04	0.04
Canton	91	68	52	119	106	87	0.07	0.06	0.04	0.09	0.09	0.07
Average	66	63	47	67	69	62	0.05	0.05	0.03	0.05	0.06	0.05
Gluten												
Manhattan	930	902	946	906	995	936	1.28	1.14	1.16	1.16	1.18	1.18
Hays	749	617	682	541	646	687	1.68	1.09	0.68	0.74	0.69	0.98
Colby	601	588	618	471	599	575	1.22	0.86	0.83	0.90	0.73	0.91
Garden City	592	632	556	478	780	608	0.92	0.82	0.74	0.70	1.00	0.83
Mound Valley	441	500	428	320	536	445	1.48	1.11	1.00	0.97	1.21	1.16
Thayer	497	516	453	371	602	488	1.22	1.01	0.88	0.88	1.01	1.00
Belleville	612	776	642	463	702	639	1.46	1.54	1.55	1.28	1.35	1.44
Canton	565	676	604	490	659	599	0.85	0.68	0.70	0.59	0.62	0.69
Average	648	652	616	505	690	622	1.26	1.03	0.94	0.90	0.97	1.02
Starch												
Manhattan	440	519	386	414	412	434	0.34	0.42	0.29	0.38	0.35	0.35
Hays	465	336	390	275	407	375	0.35	0.28	0.27	0.20	0.28	0.28
Colby	507	324	283	430	371	386	0.40	0.27	0.21	0.30	0.29	0.29
Garden City	302	349	328	317	334	326	0.25	0.28	0.25	0.22	0.28	0.26
Mound Valley	298	215	197	303	418	286	0.22	0.16	0.14	0.30	0.34	0.23
Thayer	598	327	270	287	223	341	0.45	0.26	0.22	0.24	0.19	0.27
Belleville	351	401	436	331	357	375	0.25	0.30	0.35	0.30	0.29	0.30
Canton	274	239	286	371	408	316	0.22	0.18	0.13	0.29	0.28	0.22
Average	404	341	322	341	366	355	0.31	0.27	0.23	0.28	0.29	0.28

Table 6. Distribution of potassium in the water-solubles, gluten, and starch fractions.

Station	Milligrams of potassium in the fractions from 100 grams of flour (14% M.B.)						Potassium as percentage of the ash					
	Bison	Pawnee	Ponca	Conchio	Kelkief	Ave.	Bison	Pawnee	Ponca	Conchio	Kelkief	Ave.
Water-Solubles												
Manhattan	38.19	38.42	38.67	35.86	35.08	37.24	29.1	29.7	29.7	30.1	28.4	29.2
Hays	37.75	31.67	35.95	34.86	27.98	33.64	27.2	26.6	27.1	29.6	25.0	27.1
Colby	38.82	34.01	41.99	40.43	34.43	38.10	28.4	29.3	29.6	30.4	27.5	29.0
Garden City	34.22	31.15	41.07	33.80	35.26	35.10	26.5	25.5	28.4	26.7	26.2	26.7
Mound Valley	43.33	45.43	45.29	44.20	42.24	44.06	30.3	33.4	28.9	30.2	27.6	30.1
Thayer	35.86	32.12	37.62	35.44	29.96	34.20	25.4	26.5	27.4	28.2	26.1	26.7
Belleville	36.20	28.86	37.96	34.77	28.90	33.46	28.5	25.8	29.3	29.6	25.2	27.7
Canton	36.12	32.18	39.84	36.81	34.10	35.81	28.3	25.9	28.7	28.7	27.5	27.8
Average	37.56	34.33	39.69	37.00	33.49	36.41	27.8	27.8	28.6	29.2	26.7	28.0
Gluten												
Manhattan	3.47	6.81	8.68	7.87	8.81	7.13	4.81	8.60	10.66	10.06	9.26	8.68
Hays	2.58	3.64	8.18	5.72	6.59	5.32	4.57	6.44	8.18	7.84	6.99	6.80
Colby	1.90	4.77	6.21	3.89	6.32	4.62	3.86	7.02	8.32	7.39	7.69	6.86
Garden City	2.50	5.61	5.34	4.93	5.77	4.83	3.97	7.26	7.10	7.16	7.31	6.56
Mound Valley	0.94	3.04	3.52	2.11	2.49	2.42	3.14	6.80	8.24	6.40	5.64	6.04
Thayer	2.10	3.91	4.16	2.97	4.99	3.63	5.16	7.64	8.66	7.04	8.41	7.26
Belleville	1.56	2.83	2.17	1.93	3.06	2.31	3.73	5.61	5.26	5.37	5.90	5.17
Canton	4.51	9.53	8.76	7.84	7.32	7.59	6.77	9.59	10.12	9.47	6.90	8.57
Average	2.45	5.02	5.88	4.66	5.67	4.73	4.50	7.37	8.24	7.59	7.26	6.99
Starch												
Manhattan	18.36	18.06	17.80	15.52	16.78	17.30	13.91	14.39	13.31	14.32	14.34	14.05
Hays	17.02	15.58	20.14	19.16	20.48	18.48	12.92	12.61	14.02	14.13	14.09	13.55
Colby	17.25	17.80	21.21	20.62	19.30	19.24	13.66	14.21	15.62	14.16	15.05	14.52
Garden City	16.14	17.01	19.97	16.64	18.56	17.66	13.32	13.89	15.13	14.00	15.25	14.32
Mound Valley	19.22	21.03	24.45	17.17	17.66	17.91	14.47	16.09	10.00	16.78	14.46	14.36
Thayer	21.20	18.65	20.71	18.57	17.08	19.24	16.02	15.19	16.43	15.73	14.19	15.57
Belleville	18.60	17.16	19.78	17.60	18.65	18.36	13.27	12.85	15.88	15.86	15.34	14.64
Canton	18.75	17.28	21.77	19.06	18.73	19.12	15.00	13.32	16.38	14.93	12.94	14.51
Average	18.32	17.82	19.48	18.04	18.41	18.42	14.07	14.06	14.60	14.99	14.50	14.44

Table 7. Distribution of manganese in the water-solubles, gluten, and starch fractions.

Station	Milligrams of manganese in the fractions from 100 grams of flour (14% M. B.)						Manganese as percentage of the ash					
	Bison	Pawnee	Ponca	Concho	RedChief	Ave.	Bison	Pawnee	Ponca	Concho	RedChief	Ave.
Water-Solubles												
Manhattan	0.24	0.27	0.20	0.24	0.21	0.23	0.18	0.21	0.16	0.20	0.17	0.18
Hays	0.22	0.23	0.23	0.21	0.10	0.20	0.16	0.19	0.18	0.18	0.09	0.16
Colby	0.24	0.21	0.26	0.24	0.17	0.22	0.17	0.17	0.19	0.18	0.13	0.17
Garden City	0.27	0.26	0.34	0.34	0.27	0.30	0.20	0.22	0.23	0.27	0.20	0.22
Mound Valley	0.28	0.24	0.25	0.26	0.21	0.25	0.20	0.18	0.16	0.18	0.14	0.17
Thayer	0.09	0.18	0.24	0.24	0.14	0.18	0.07	0.15	0.18	0.20	0.12	0.14
Belleville	0.20	0.19	0.25	0.13	0.01	0.16	0.16	0.17	0.20	0.12	0.01	0.13
Canton	0.18	0.12	0.19	0.19	0.21	0.18	0.16	0.09	0.14	0.15	0.17	0.14
Average	0.22	0.21	0.24	0.23	0.16	0.21	0.16	0.17	0.18	0.18	0.13	0.17
Gluten												
Manhattan	0.06	0.06	0.09	0.09	0.13	0.09	0.08	0.07	0.10	0.11	0.14	0.10
Hays	0.25	0.06	0.33	0.22	0.19	0.21	0.42	0.12	0.34	0.32	0.19	0.28
Colby	0.15	0.12	0.14	0.13	0.20	0.15	0.29	0.18	0.20	0.25	0.24	0.23
Garden City	0.15	0.27	0.24	0.28	0.15	0.22	0.22	0.34	0.31	0.40	0.20	0.29
Mound Valley	0.05	0.04	0.07	0.03	0.07	0.05	0.20	0.10	0.18	0.07	0.17	0.14
Thayer	0.05	0.04	0.07	0.05	0.08	0.06	0.12	0.09	0.15	0.09	0.14	0.12
Belleville	0.06	0.05	0.05	0.04	0.03	0.05	0.14	0.12	0.11	0.11	0.04	0.10
Canton	0.07	0.11	0.09	0.08	0.17	0.10	0.09	0.12	0.12	0.09	0.15	0.11
Average	0.11	0.09	0.14	0.12	0.13	0.12	0.20	0.14	0.19	0.18	0.16	0.17
Starch												
Manhattan	0.12	0.17	0.17	0.12	0.13	0.14	0.11	0.13	0.12	0.10	0.09	0.11
Hays	0.12	0.18	0.18	0.18	0.14	0.16	0.10	0.14	0.12	0.16	0.10	0.12
Colby	0.19	0.19	0.17	0.19	0.13	0.17	0.14	0.14	0.12	0.12	0.09	0.12
Garden City	0.12	0.12	0.29	0.18	0.26	0.19	0.10	0.11	0.23	0.16	0.20	0.16
Mound Valley	0.25	0.26	0.19	0.21	0.22	0.23	0.18	0.18	0.19	0.23	0.16	0.19
Thayer	0.19	0.17	0.18	0.13	0.20	0.17	0.16	0.14	0.14	0.13	0.15	0.14
Belleville	0.18	0.18	0.25	0.21	0.21	0.21	0.14	0.13	0.18	0.15	0.15	0.15
Canton	0.17	0.16	0.23	0.13	0.13	0.16	0.12	0.14	0.15	0.11	0.11	0.13
Average	0.17	0.18	0.21	0.17	0.18	0.18	0.13	0.14	0.16	0.14	0.13	0.14

Table 8. Distribution of magnesium in the water-solubles, gluten, and starch fractions.

Station	Milligrams of magnesium in the fractions from 100 grams of flour (14% M.B.)						Magnesium as percentage of the ash					
	Alson	Pawnee	Ponca	Concho	RedChief	Ave.	Alson	Pawnee	Ponca	Concho	RedChief	Ave.
Water-Solubles												
Manhattan	10.68	12.84	12.38	16.00	9.72	12.32	7.77	10.07	9.70	13.35	7.95	9.77
Hays	11.16	12.84	11.39	13.24	11.54	12.03	7.54	11.01	8.86	11.18	10.20	9.76
Colby	10.78	13.25	16.19	13.83	12.18	13.25	7.28	11.09	11.31	10.29	9.81	9.96
Garden City	9.20	18.29	13.34	0.00	12.60	10.69	7.09	14.88	9.25	0.00	9.23	8.09
Mound Valley	12.66	11.13	13.83	1.94	13.88	10.69	8.95	8.16	8.95	1.51	9.06	7.33
Thayer	10.85	12.80	13.83	12.04	6.27	11.16	8.88	10.85	10.09	9.70	5.40	8.98
Belleville	9.02	11.36	7.07	7.85	7.45	8.55	6.96	10.32	5.46	6.71	6.44	7.18
Canton	9.82	10.08	6.84	12.93	11.10	10.75	8.44	8.18	4.83	10.08	11.36	8.58
Average	10.52	12.82	11.86	9.73	10.97	11.18	7.86	10.57	8.56	7.85	8.68	8.70
Gluten												
Manhattan	0.58	0.96	0.99	1.39	1.46	1.08	0.80	1.22	1.24	1.76	1.52	1.31
Hays	0.68	0.20	2.00	1.38	1.40	1.13	1.20	3.71	2.00	1.91	1.48	2.06
Colby	0.86	1.22	1.69	0.69	2.23	1.34	1.74	1.79	2.26	1.32	2.71	1.96
Garden City	0.85	0.72	1.01	0.98	1.40	1.00	1.36	0.93	1.34	1.42	1.79	1.37
Mound Valley	0.33	0.77	0.98	0.73	0.86	0.73	1.09	1.72	2.29	2.21	1.96	1.85
Thayer	0.78	0.98	1.08	1.11	1.25	1.04	1.93	2.44	2.10	2.64	2.10	2.24
Belleville	0.77	0.95	0.72	0.60	1.21	0.85	1.83	1.89	1.73	1.64	2.32	1.88
Canton	1.60	3.27	2.55	2.04	2.52	2.40	2.11	3.29	2.96	2.46	2.38	2.70
Average	0.81	1.13	1.38	1.12	1.54	1.20	1.55	2.12	2.00	1.92	2.03	1.92
Starch												
Manhattan	1.69	2.21	1.83	2.27	3.08	2.22	1.33	1.86	1.49	1.81	2.51	1.80
Hays	2.89	2.94	2.81	3.21	3.45	3.06	2.21	2.40	2.09	2.52	2.35	2.31
Colby	3.26	3.62	3.84	2.98	2.74	3.29	2.11	2.64	2.77	2.04	2.19	2.41
Garden City	2.85	2.29	2.21	1.76	1.22	2.07	2.24	1.87	1.70	1.42	0.93	1.63
Mound Valley	1.11	0.68	0.42	1.97	2.10	1.26	0.89	0.50	0.43	2.15	1.50	1.09
Thayer	1.92	2.27	2.32	2.53	2.58	2.32	1.50	1.84	1.84	2.04	2.10	1.86
Belleville	2.37	2.57	2.85	3.56	3.58	2.99	1.84	2.01	2.36	2.81	2.88	2.38
Canton	3.14	2.94	2.85	2.46	2.50	2.78	2.44	2.28	2.09	1.84	1.89	2.11
Average	2.40	2.44	2.39	2.59	2.66	2.50	1.86	1.92	1.85	2.08	2.04	1.95

Table 9. Distribution of sodium in the water-solubles, gluten, and starch fractions.

Station	Milligrams of sodium in the fractions from 100 grams of flour (14% M.B.)						Sodium as percentage of the ash					
	Bison	Pawnee	Ponca	Concho	RedChief	Ave.	Bison	Pawnee	Ponca	Concho	RedChief	Ave.
Water-Solubles												
Manhattan	3.02	2.71	3.26	3.50	3.14	3.13	2.22	2.10	2.50	2.94	2.54	2.46
Hays	3.00	3.22	3.74	3.00	3.25	3.24	2.16	2.70	2.80	2.55	2.91	2.62
Colby	2.75	3.06	3.17	2.95	2.65	2.92	2.02	2.58	2.24	2.21	2.12	2.23
Garden City	3.02	2.68	3.56	2.98	3.32	3.11	2.34	2.68	2.46	2.36	2.46	2.46
Mound Valley	1.91	1.99	3.23	3.57	5.20	3.18	1.34	1.47	2.06	2.45	3.40	2.14
Thayer	3.33	3.14	4.27	3.05	3.11	3.38	2.36	2.66	3.12	2.43	2.70	2.65
Belleville	2.75	2.98	2.64	2.70	3.50	2.91	2.17	2.67	2.09	2.30	3.06	2.46
Canton	2.79	3.51	3.36	3.08	3.94	3.34	2.19	2.83	2.41	2.40	3.18	2.60
Average	2.82	2.91	3.40	3.10	3.51	3.15	2.10	2.46	2.46	2.46	2.80	2.45
Gluten												
Manhattan	0.66	0.92	0.60	0.64	0.66	0.70	0.93	1.16	0.73	0.82	0.70	0.87
Hays	0.53	0.34	0.59	0.46	0.46	0.46	0.96	0.63	0.59	0.55	0.49	0.64
Colby	0.41	0.47	0.50	0.27	0.36	0.40	0.85	0.70	0.67	0.51	0.44	0.63
Garden City	0.37	0.57	0.31	0.30	0.51	0.41	0.58	0.74	0.41	0.46	0.66	0.57
Mound Valley	0.33	0.45	0.23	0.24	0.15	0.28	1.09	1.00	0.55	0.76	0.35	0.75
Thayer	0.32	0.56	0.42	0.23	0.42	0.39	0.77	0.96	0.82	0.56	0.70	0.76
Belleville	0.33	0.36	0.25	0.21	0.37	0.30	0.78	0.72	0.62	0.57	0.69	0.68
Canton	0.46	1.25	0.41	0.51	0.51	0.63	0.69	1.26	0.48	0.63	0.48	0.71
Average	0.43	0.62	0.41	0.35	0.43	0.45	0.83	0.90	0.61	0.61	0.56	0.70
Starch												
Manhattan	1.45	0.85	1.20	1.67	1.88	1.41	1.09	0.67	0.91	1.56	1.58	1.16
Hays	1.00	0.84	0.58	0.62	0.68	0.74	0.78	0.68	0.42	0.44	0.46	0.56
Colby	1.25	1.50	1.22	1.02	1.20	1.24	0.97	1.23	0.94	0.71	0.89	0.95
Garden City	1.09	0.90	0.86	0.69	1.63	1.03	0.89	0.74	0.66	0.63	1.29	0.84
Mound Valley	0.98	1.30	1.04	1.53	1.80	1.33	0.74	0.99	0.73	1.54	1.51	1.10
Thayer	1.30	0.87	1.09	1.09	0.88	1.05	0.97	0.68	0.83	0.90	0.74	0.82
Belleville	1.38	0.92	1.26	1.26	1.26	1.22	1.00	0.69	1.00	1.28	1.05	1.00
Canton	0.79	0.96	1.70	1.14	3.01	1.52	0.64	0.72	1.29	0.85	2.06	1.11
Average	1.16	1.02	1.12	1.13	1.54	1.19	0.89	0.80	0.85	0.99	1.20	0.94

Table 10. Distribution of calcium in the water-solubles, gluten, and starch fractions.

Station	Milligrams of calcium in the fractions from 100 grams of flour (11% M. B.)						Calcium as percentage of the ash					
	Elgin	Pawnee	Ponca	Concho	Red Chief	Ave.	Elgin	Pawnee	Ponca	Concho	Red Chief	Ave.
Water-Solubles												
Manhattan	2.21	3.54	6.98	1.68	2.49	3.38	1.63	2.74	5.38	1.39	2.00	2.63
Hays	2.00	8.60	4.38	4.36	1.51	4.17	1.44	7.21	3.30	3.68	1.35	3.40
Colby	2.32	7.24	9.54	4.27	2.27	5.13	1.70	6.09	6.73	3.20	1.81	3.91
Garden City	2.09	6.23	7.18	2.98	2.25	4.15	1.62	5.14	4.96	2.36	1.66	3.15
Mound Valley	3.34	2.90	8.79	7.47	3.11	5.12	2.34	2.15	5.60	5.13	2.05	3.45
Thayer	2.58	6.52	6.82	3.70	2.55	4.43	1.82	5.49	4.98	2.94	2.24	3.49
Belleville	2.30	9.18	3.98	9.15	2.45	5.41	1.82	8.18	3.15	7.77	2.15	4.61
Canton	2.29	9.91	5.52	8.26	2.23	5.64	1.79	7.99	3.98	6.45	1.79	4.40
Average	2.39	6.76	6.65	5.23	2.36	4.68	1.77	5.62	4.76	4.12	1.88	3.63
Gluten												
Manhattan	3.22	1.51	1.45	1.15	2.43	1.95	4.46	1.92	1.78	1.48	2.55	2.44
Hays	1.77	1.11	2.00	1.24	0.89	1.40	3.12	1.98	1.96	1.70	0.95	1.94
Colby	1.11	2.14	2.01	1.09	1.66	1.60	2.24	3.14	2.69	2.08	2.01	2.43
Garden City	1.46	1.24	1.30	1.26	1.52	1.36	2.32	1.62	1.75	1.83	1.93	1.89
Mound Valley	1.46	2.08	1.26	1.92	1.59	1.66	4.92	4.65	2.95	5.81	3.57	4.38
Thayer	1.34	1.58	1.93	1.35	1.55	1.55	3.29	3.15	3.74	3.20	2.63	3.20
Belleville	1.37	1.52	1.69	1.39	1.50	1.49	3.27	3.00	4.08	3.85	2.89	3.42
Canton	1.55	1.83	1.57	2.33	1.42	1.74	2.35	1.84	1.81	2.82	1.35	2.03
Average	1.66	1.63	1.65	1.47	1.57	1.60	3.25	2.66	2.60	2.85	2.24	2.72
Starch												
Manhattan	1.51	1.53	1.48	1.67	1.38	1.51	1.17	1.26	1.23	1.36	1.13	1.23
Hays	1.53	1.50	1.64	1.79	1.49	1.59	1.13	1.23	1.18	1.38	1.03	1.19
Colby	1.82	1.87	1.95	1.90	1.47	1.80	1.34	1.35	1.38	1.34	1.17	1.32
Garden City	1.82	1.57	1.60	1.64	1.50	1.63	1.42	1.28	1.25	1.30	1.14	1.28
Mound Valley	1.83	1.91	1.60	1.75	1.95	1.81	1.46	1.49	1.70	1.95	1.48	1.62
Thayer	1.78	1.70	1.67	1.98	1.49	1.72	1.35	1.37	1.37	1.66	1.26	1.40
Belleville	1.84	1.72	1.86	2.33	1.61	1.87	1.47	1.30	1.50	1.85	1.25	1.47
Canton	1.45	1.58	1.70	1.96	1.48	1.63	1.17	1.22	1.23	1.50	1.07	1.24
Average	1.70	1.67	1.69	1.88	1.55	1.70	1.31	1.31	1.36	1.54	1.19	1.34

Table 11. Summary of F values from analyses of variance for the ash and elemental composition of the flour fractions.

	Water-Soluble		Gluten		Starch	
	Location	Varieties	Location	Varieties	Location	Varieties
	F	F	F	F	F	F
Amount of ash and elemental composition of the fractions from 100 g. of flour (14% M. B.)						
Ash	9.45**	10.70**	28.54**	11.85**	2.64*	0.88
Phosphorus	8.36**	16.21**	32.77**	7.81**	6.70**	1.52
Iron	2.67*	1.22	21.30**	7.64**	1.68	1.24
Potassium	15.23**	12.33**	20.44**	16.96**	0.92	1.07
Manganese	4.95**	3.48*	10.43**	0.96	2.47**	1.40
Magnesium	0.74	0.86	9.17**	4.30**	8.02**	0.42
Sodium	0.51	2.46	5.73**	4.22**	2.01	2.18
Calcium	0.73	9.49**	0.85	0.23	3.86**	5.57**
Ash as percent of the flour fractions (14% M. B.) and individual elements as percent of the ash from the flour fractions						
Ash	4.42**	7.57**	9.73**	10.58**	11.23**	5.32**
Phosphorus	16.91**	28.13**	2.12	10.69**	2.25	1.11
Iron	2.62*	1.97	11.61**	7.04**	2.09	1.61
Potassium	5.31**	4.75**	11.26**	26.69**	0.88	0.66
Manganese	3.31*	3.08*	8.54**	0.97	4.00**	1.12
Magnesium	0.76	1.24	4.24**	1.67	5.09**	0.46
Sodium	1.30	3.75*	1.82	7.79**	2.05	2.05
Calcium	0.85	9.63**	7.97**	2.26	11.69**	14.39**

of the total flour ash. Ash content of the complexes varied greatly. The water-solubles were highest in ash content ranging from 21.6 to 38.1 and averaging 29.4 mg. per gram. The gluten samples contained from 3.3 to 5.7 and averaged 4.2 mg. of ash per gram. Starch was extremely low in ash ranging from 1.3 to 2.4 and averaging 2.0 mg. per gram. Location and varietal differences with respect to ash content of the water-solubles, gluten, and starch were highly significant.

The water-solubles contained approximately 18, the gluten 36, and the starch 46 percent of the total flour phosphorus. Phosphorus averaged 9.97 percent of the water-solubles ash, 39.72 percent of the gluten ash, and 25.53 percent of the starch ash. Location was responsible for the greatest variation in phosphorus content of the flour fractions. Location and varietal differences in phosphorus content of the water-solubles and gluten fractions were highly significant, while only locational differences were significant for the starch fraction. Percentagewise, location and variety differences in phosphorus content of the water-solubles ash were highly significant. Location differences in gluten ash were insignificant, but variations among varieties were highly significant. Differences in phosphorus content of the starch ash were insignificant for both varieties and locations.

Approximately 6 percent of the total iron was in the water-solubles, 62 percent in the gluten, and 32 percent in the starch complex. The water-solubles ash averaged 0.06 iron, the gluten ash 1.02 percent and the starch ash 0.28 percent. Locational differences in iron content of the water-solubles and water-solubles ash were significant at the 5 percent level. Variety and location differences were highly significant for iron content of the gluten

and gluten ash. There were no significant differences in the iron content of the starch or starch ash.

The flour potassium was distributed among the complexes as follows: 61 percent in the water-solubles, 8 percent in the gluten, and 31 percent in the starch. The water-solubles ash averaged 28.0 percent potassium, the gluten ash 7.0 percent and the starch ash 14.4 percent. Potassium content of the water-solubles and gluten of their ashes varied significantly with location and variety. There were no significant differences in potassium content of starch and starch ash.

Approximately 60 percent of the flour calcium was in the water-solubles complex, the remainder was almost equally divided between the starch and gluten. The water-solubles ash averaged 3.63 percent calcium, the gluten ash 2.72 percent, and the starch ash 1.34 percent. Calcium content of the water-solubles and water-solubles ash varied significantly with variety, while the calcium content of the gluten ash varied significantly with location. Both location and variety differences in calcium content of the starch and starch ash varied significantly.

Two-thirds of the flour sodium was in the water-solubles complex, one-fourth in the starch, and the remainder in the gluten. The water-solubles ash averaged 2.45 percent sodium, but sodium was responsible for less than one percent of the weight of the gluten and starch ashes. There were no significant differences in sodium content of the water-solubles, but varietal differences in sodium content of the water-solubles ash were significant. Sodium content of the gluten varied significantly with variety and location. In the gluten and gluten ash, only varietal differences were significant for this element.

Three-fourths of the flour magnesium was recovered in the water-solubles, 8 percent in the gluten, and 17 percent in the starch. The water-solubles ash contained 8.78 percent magnesium, while the gluten and starch ashes contained less than 2 percent. Magnesium content of the gluten varied significantly with variety and location, but only significantly with location in the gluten ash.

Approximately 41 percent of the manganese in the flour was recovered in the water-solubles, 24 percent in the gluten, and 35 percent in the starch fraction. Manganese was responsible for less than 0.2 percent of the ash in the flour complexes. Concentration of this element varied significantly among locations in all three fractions. In the water-solubles ash, manganese varied significantly with respect to location and variety. In the gluten and starch ashes, significant differences in manganese were due to locational effects only.

Relationship Between Mineral Composition and Baking Quality

Correlations as high as +0.98 between flour protein and loaf volume have been reported in the literature (Miller and Johnson, 25). A similar correlation coefficient for the present data was +0.54, which, although significant, is insufficient for prediction purposes. This low figure provides further evidence that the protein quality of at least some of the samples used in this study was inferior. The correlation between flour ash and gluten quality (r=-0.569***) was comparable with that for flour protein and loaf volume (r=+0.542***).

It is well known that proteins bind salts with significant effects on their physical properties. Swanson (40) discussed the effects of various

salts on flour doughs and dispersibility of flour proteins. Data obtained in the present work substantiates the contention that minerals have important effects on flour proteins and gluten quality as reflected by protein content and loaf volume.

The correlations between gluten quality score and total ash, and between gluten quality score and elemental composition of the flour fractions are summarized in Table 12. These data indicate that as the ash content of the gluten increases, the gluten quality score decreases. The correlation between these factors was -0.818. Each of the elements determined, except calcium, contributed in this effect. Phosphorus, the major component of ash (12-32%), apparently was the main factor in this effect on gluten quality. The high correlation between ash content of the gluten and gluten quality score, and between phosphorus content of the gluten and gluten quality score (-0.84) suggests that either ash or phosphorus content of the gluten is more reliable than flour protein for predicting the breadmaking quality of flour. This is an observation which has not been reported previously. Further work relating phosphorus content to quality appears warranted. The phosphorus content of water-solubles and starch also were significantly and negatively correlated with gluten quality score. This may indicate that the major portion of flour phosphorus was combined in some way with the gluten during mixing and thereby affected its physical characteristics.

The potassium, manganese, and calcium concentrations of the starch, and potassium concentration of the water-solubles were correlated significantly and positively with gluten quality score. This suggests that the binding of these elements by the water-solubles and starch prevented them from having a detrimental influence on gluten properties. Further work should be done

Table 12. Coefficients of correlation between gluten quality score, ash, and concentration (mg. in flour fraction from 100 g. flour) of certain inorganic elements in the flour fractions.

Variables Correlated	Degree of Freedom	Flour Fractions		
		Gluten	Starch	Water-Solubles
		r	r	r
Quality score vs. ash	38	-0.818***	n. s.	n. s.
Quality score vs. phosphorus	38	-0.814***	-0.395*	-0.410**
Quality score vs. iron	38	-0.518***	n. s.	n. s.
Quality score vs. potassium	38	-0.636***	-0.389**	+0.383*
Quality score vs. manganese	38	-0.637***	+0.474**	n. s.
Quality score vs. magnesium	38	-0.439**	n. s.	n. s.
Quality score vs. sodium	38	-0.521***	n. s.	n. s.
Quality score vs. calcium	38	n. s.	+0.570***	n. s.

n. s. = non-significant

to determine what effect mixing doughs to optimum development would have on the distribution of the various elements among the three flour complexes. It is possible that mechanical mixing, rather than the gentle treatment used in separation of the fractions for the present study, would cause more of the elements to combine with the gluten proteins. Conceivably, this might result in higher correlations between elemental composition of the gluten and gluten quality score.

SUMMARY AND CONCLUSIONS

This investigation of the mineral composition of gluten, starch, and water-solubles fractions of hard wheat flour and its relationship to flour quality has led to the following conclusions:

1. Environment was more important than variety in determining flour quality and mineral composition of the flour and flour fractions.

2. Gluten quality score gave a better measure of flour quality than did loaf volume.

3. Concentration of ash or phosphorus in the gluten was a better measure of flour quality than flour protein or loaf volume.

4. Mineral content of the flour and gluten was significantly and negatively correlated with gluten quality score. Each element determined, except calcium, contributed to this effect.

5. Phosphorus, iron, potassium, sodium, manganese, and magnesium concentration of the gluten were each significantly and negatively correlated with flour quality.

6. The concentration of phosphorus in the water-solubles was significantly and negatively correlated, while the potassium content was significantly and positively correlated with gluten quality score.

7. Concentrations of potassium, calcium, and magnesium in the starch were significantly and negatively correlated with gluten quality score.

8. In general, the elemental composition of gluten was more highly correlated with gluten quality score than was the elemental composition of water-solubles and starch.

SUGGESTIONS FOR FUTURE WORK

The investigation reported here was of the survey type. It was designed to determine specific areas for further and more intensive investigations. The results have suggested the following for future work:

1. A study of the relationships between phosphorus content of whole wheat and flour, and baking quality. These samples should include those high in protein, low in ash and low in quality. These can usually be obtained from Chillicothe and Denton, Texas, and certain stations in Oklahoma.

2. A study of the relationship between protein and phosphorus concentrations of bread type flours.

3. A study of the distribution of mineral elements in the gluten, water-solubles and starch separated from doughs mixed to optimum development.

4. A study of the concentrations and types of phosphorus occurring in flour and flour fractions.

5. A study of the relationships among sedimentation values, valorimeter values, phosphorus concentrations, and gluten quality score.

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APPENDIX

Preparation of Flour Fractions

Flour (250 g., 14% moisture basis) was shaken vigorously for one minute in a 2000 ml. Erlenmeyer flask with 550 ml. of cold (2-4°C) distilled water. The flour slurry was transferred to centrifuge tubes (one pint milk bottles) with 50 ml. of cold distilled water and centrifuged for 20 minutes at 1000 rpm in an International Centrifuge (Model V). The supernatant was decanted from one of the centrifuge bottles into a 2000 ml. enamel beaker. The dough was removed from this centrifuge bottle with a stainless steel spatula and placed in the decanted liquid. The supernatant from each succeeding centrifuge bottle was used to rinse the previously emptied bottle and the dough added to that in the enamel beaker.

The combined dough pieces from the 250 g. of flour were kneaded gently in the liquid until a good separation of gluten and starch was obtained. The gluten then was placed in a small bowl and the liquid containing the suspended starch passed through a 40 mesh silk cloth sieve. Any gluten remaining on the sieve was collected and added to the washed portion. The gluten was rewashed for two minutes in each of six successive 40 ml. aliquots of cold (2-4°C) distilled water. Each aliquot of wash water was passed through the sieve into the starch solution.

The washed gluten mass was placed in a refrigerator for one hour after which any remaining liquid was discarded, and the gluten weighed and sliced into long strips. These strips were frozen on the interior of wide-mouthed, quart Mason jars which previously had been cooled to approximately -70°C. on dry ice. The gluten strips were spread quickly to cover a large area using stainless steel crucible tongs. The frozen gluten was stored in a deepfreeze at -20°C. until lyophilized.

The water-solubles were separated from the starch by passing the starch suspension through a Sharples Super-Centrifuge (Type T 1), the speed of which was controlled by a "Variac". Approximately one-half of the starch suspension was passed through the centrifuge at one-half speed in order to spread the starch evenly within the rotating cylinder. The speed was then increased to full for 3 minutes to pack the starch, after which it was reduced to one-half. The remaining starch suspension was passed through at this setting. The centrifuge was rinsed with 25 ml. of distilled water and the liquid (water-soluble) fraction measured. Duplicate 10 ml. aliquots were taken for protein analysis and the remainder was shell-frozen immediately on the interior of a one gallon glass jar by mechanically rotating the jar in methyl-cellosolve (ethylene glycol monomethyl ether) cooled to -70°C. with dry ice. The frozen solution was stored at -20°C. until lyophilised.

The starch and dextrin fractions were removed from the centrifuge, weighed, placed on a glass plate, and mixed thoroughly with a large stainless steel spatula. Drying at room temperature was accelerated by frequent sub-dividing and mixing under a current of air from a fan.

The frozen gluten and water-solubles were dried by lyophilizing at a pressure between 50 and 100 microns.

Ashing Methods (1)

New Coors No. 170 porcelain crucibles were used for ashing the samples. Prior to use, they were heated in a muffle furnace at 520°C. for 16 hours. After cooling, they were washed in concentrated hydrochloric acid and rinsed in distilled water.

An appropriate amount of sample was weighed into a crucible and placed

in a muffle furnace adjusted to 520°C. To prevent the starch and gluten samples from puffing out of the crucibles, it was necessary to ignite the first vapors given off. The samples were allowed to remain in the furnace until carbon-free. The starch and water-solubles samples required 12 to 18 hours. Many gluten samples required heating for 72 hours. The ash was weighed and stored in glass vials until analysis for minerals could be made.

Determination of Total Phosphorus (32)

Preparation of Solutions. The concentrated reduced molybdate reagent was prepared by weighing 39.12 g. of reagent grade molybdic anhydride into a round bottomed pyrex flask, adding 800 ml. of concentrated sulfuric acid, and heating at 150°C. with stirring, until solution was complete, as indicated by a clear, greenish color. After the quantitative addition of 2.2 g. of powdered molybdenum metal (99.5 percent Mo), heating and stirring was resumed until solution was complete. The deep-blue solution was cooled, transferred quantitatively to a one liter volumetric flask, and diluted to volume with concentrated sulfuric acid.

The dilute reduced molybdate solution was prepared by pipetting 10 ml. of the concentrated reduced molybdate reagent into a 100 ml. volumetric flask containing about 50 ml. of distilled water. The pipette was rinsed with distilled water, the rinsings added to the flask, and the solution diluted to volume with distilled water. A fresh solution of this reagent was prepared each day.

The concentrated stock phosphate solution was prepared by dissolving 4.3929 g. of A. C. S. grade dry monobasic potassium phosphate in 300 ml. of distilled water and 200 ml. of 1 N sulfuric acid contained in a one liter

volumetric flask. Several drops of 0.1 N potassium permanganate were added and the solution diluted to volume with distilled water. This solution contained 1.0 mg. of phosphorus per ml. and was found to be stable.

The diluted stock phosphate solution containing 0.01 mg. of phosphorus per ml. was prepared by diluting the concentrated stock solution 1:100. A fresh solution of this reagent was prepared each day.

Digestion of Samples. An appropriate amount of sample (300 mg. of water-solubles, 300 mg. of gluten, or 400 mg. of starch) was weighed into a 100 ml. Micro-Kjeldahl flask. Three ml. of concentrated sulfuric acid and two, 6 mm., glass beads were added. The sample was heated until all organic material was charred and a homogenous solution obtained. After cooling, four drops of 30 percent hydrogen peroxide were added and the solution was heated until colorless. It usually was necessary to add additional peroxide up to a total of 10 drops with intermittent heating and cooling. The solution was heated for 10 minutes after the last addition of peroxide. When cool, 20 ml. of water was added and the solution boiled for 5 minutes to remove remaining peroxide and insure conversion of phosphorus to the ortho form. After cooling, the solution was quantitatively transferred to a 100 ml. volumetric flask and diluted to volume. This sample solution was used for the colorimetric determination of phosphorus.

Colorimetric Determination of Phosphorus. A suitable aliquote of the sample solution (standard phosphate, 5 ml. of water-solubles, 10 ml. of starch, or 10 ml. of gluten solution) was transferred to a 100 ml. volumetric flask. Sufficient 3.60 N sodium hydroxide was added to neutralize the acidity. Two drops of indicator, 0.2 percent aqueous solution of sodium alizarin sulfonate, were added and the acidity adjusted with 1.0 N sulfuric

acid and 1.0 N sodium hydroxide until one drop of the acid turned the solution yellow. The solution was then diluted to approximately 70 ml. with distilled water. A reagent blank was prepared using the same amount of 3.60 N alkali as for the samples and the acidity adjusted in the same manner. A ten ml. aliquot of the reduced molybdate reagent was added to the blank and each sample solution. All flasks were mixed by swirling and placed in a boiling water bath for exactly 30 minutes. After cooling in a cold water bath, the reaction solutions were diluted to volume with distilled water. Intensity of the color was read in a Bausch and Lomb "Spectronic 20" colorimeter at 820 mμ. Using the reagent blank, the instrument was set at 100 percent transmission. Milligrams of phosphorus in the sample aliquot was determined by reference to the standard curve.

Preparation of Calibration Curve. Aliquots of 0.0, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 10.0, and 12.0 ml. of the diluted phosphate solution (0.01 mg. of phosphorus per ml.) were pipetted into 100 ml. volumetric flasks. Two drops of indicator and one drop of 1 N sulfuric acid were added and the solution diluted to approximately 70 ml. with distilled water. After adding 10 ml. of reduced molybdate solution, the procedure outlined above for treatment of the sample aliquot was followed. The standard containing no phosphorus was used to set the instrument at 100 percent transmission. The logarithms of the transmittance values obtained for the standards were plotted against the known phosphorus concentrations to obtain the calibration curve.

Quantitative Estimation of Iron (2)

Preparation of Solutions. The complexing reagent was prepared by dissolving 0.1 g. of alpha, alpha-dipyridyl in distilled water and diluting to 100 ml. with water.

The reducing solution was prepared by diluting 10 g. of hydroxylamine hydrochloride to 100 ml. with water.

The acetate buffer was prepared by diluting 8.3 g. of anhydrous sodium acetate (previously dried at 100°C) and 12 ml. of glacial acetic acid to 100 ml. with water.

Preparation of Reference Curve. The concentrated stock solution of iron was prepared containing 3.512 grams of iron ammonium sulfate-hexahydrate and two drops of concentrated hydrochloric acid per 500 ml. of solution. The final stock solution containing 0.01 mg. of iron per ml. was prepared by diluting 10.0 ml. of the concentrated stock solution to one liter.

The standard iron solutions consisted of 2.0, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0, and 45.0 ml., respectively, of the final diluted iron stock solution and 2.0 ml. of concentrated hydrochloric acid diluted to 100 ml. with water. The blank solution contained 2.0 ml. of concentrated hydrochloric acid diluted to 100 ml. with distilled water. Ten ml. of each of the standard iron solutions and the blank were used in the procedure involving one colorimetric determination of iron (Appendix).

Preparation of Sample Solutions. An appropriate amount of flour fraction (5 g. of gluten, 5 g. of starch, or 2 g. of water-solubles) was ashed according to the method given in the appendix. The ash residues were dissolved in 2 ml. of concentrated hydrochloric acid and evaporated to dry-

ness. Each residue was taken up in 2 ml. of concentrated hydrochloric acid, warmed gently, filtered quantitatively into a volumetric flask (25 ml. for gluten and starch, 50 ml. for water-solubles), and diluted to volume with water. Whatman No. 42 filter paper was used.

Colorimetric Determination of Iron. An appropriate aliquot of the sample solution (10 ml. water-solubles, 3 ml. gluten, or 15 ml. starch) was pipetted into a 25 ml. volumetric flask, and 1.0 ml. of hydroxylamine hydrochloride added. After standing for a few minutes, 5.0 ml. of the acetate buffer solution and 2.0 ml. of the alpha, alpha-dipyridyl solution were added and the solution diluted to volume. The solutions were allowed to stand for 30 minutes, and the intensity of color in each was read in a Bausch and Lomb "Spectronic 20" colorimeter at 515 mμ. The blank solution was used to set the instrument at 100 percent transmission. The iron concentration of these solutions were determined from the calibration curve.

Flame Photometry (4)

Instrument. A Beckman Model D. U. spectrophotometer equipped with a Beckman 9200 flame photometry attachment and Beckman atomiser-burner assembly was used.

Sample Preparation. Known quantities of ash were dissolved in 2.0 ml. of concentrated hydrochloric acid and evaporated just to dryness on a hot-plate. The residue was taken up in exactly 2.0 ml. of concentrated hydrochloric acid, and warmed gently on a hot-plate. The solutions of ash from the water-solubles were filtered and made up to 50.0 ml. with distilled water. The solutions from the starch and gluten were made up to 25 ml. with distilled water. These solutions were stored in a refrigerator to prevent mold growth.

Stock Solutions. The stock solutions for preparation of the standard solutions were prepared according to the following:

Stock Solutions	Concentration of the element	Salt Used	Weight of Salt
	µg/ml.		g./liter
Sodium	1000	NaCl	2.542
Potassium	1000	KCl	1.907
Calcium	1000	$CaCO_3$*	2.497
Manganese	200	$MnCl_2 \cdot 4H_2O$	0.720
Magnesium	5000	$Mg(C_2H_3O_2)_2 \cdot 4H_2O$*	44.093

* The salt was dissolved in 6.0 N hydrochloric acid, heated gently, and quantitatively transferred to a one liter volumetric flask.

Preparation of Standard Solutions. The material remaining after the moisture determinations was composited according to fraction, mixed, ashed, and analyzed. This information was useful in determining the concentrations of interferring ions necessary for the standard solutions.

The standard solutions were prepared by appropriate dilutions of the stock solutions. Each contained the interferring elements in the approximate concentration expected in the sample solutions, and hydrochloric acid in the same concentration as in the sample solutions. At least 4 ml. of concentrated hydrochloric acid per 100 ml. of standard was necessary to inhibit mold growth. Up to 8 ml. of the acid per 100 ml. gave satisfactory results.

The standard solutions for preparation of the standard curve were prepared according to the following:

Element Analyzed	Range of Standards	Interferring elements added	Remarks
	µg/ml.		
Potassium	0-100	Sodium	
Sodium	0-100	Potassium	Range reduced when concentration of samples permitted.
Calcium	0-100	Sodium, and Potassium	Range reduced when concentration of samples permitted.

Element Analyzed	Range of Standards µg/ml.	Interferring elements added	Remarks
Manganese	0-20	Sodium, Potassium, and Calcium	Range could be extended when necessary.
Magnesium	0-250	Sodium, Potassium, and Calcium	

Operation of the Flame Photometer. An oxygen-acetylene flame was used with an acetylene pressure of four pounds per square inch and the oxygen pressure recommended for the burner. The red-sensitive phototube was used with a 2000 megohm resistor. The instrument was operated with the selector switch at the 0.1 position and the photomultiplier set on "full". The slit-width was adjusted to give a reading of 100 percent transmission when the most concentrated standard was atomized with the sensitivity control set near the counter-clockwise limit. The sensitivity control seldom needed further adjustment if the dark-current remained properly adjusted.

Readings were made on each standard, beginning with the least concentrated one. A standard curve was prepared by plotting the average of duplicate readings for each standard against the element concentration in µg. per ml.

Successive readings were made on four to ten sample solutions depending on stability of the instrument. The instrument adjustment was checked after each sample group by reading several standards covering the concentration range of the sample solutions. The series of samples was re-read in reverse order. Whenever duplicate readings varied by more than one percent transmission, the instrument adjustment was checked and the samples read again. Concentrations of the sample solutions were determined by reference to the standard curve.

Wavelengths and approximate slit-widths used for measuring the elements were as follows:

Element	Wavelengths	Slit-width
	mμ.	mm.
Potassium	770	0.11
Sodium	589	0.0125
Calcium	554	0.040
Manganese	403.3	0.045
Magnesium	383.0	0.050

MINERAL COMPOSITION OF GLUTEN, STARCH, AND WATER-SOLUBLES FRACTIONS OF WHEAT FLOUR AND ITS RELATIONSHIP TO FLOUR QUALITY

by

ROBERT KEEBLER BEQUETTE

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The influence of environment and variety on the total ash and elemental composition of the water-solubles, gluten, and ash complexes separated from forty hard red winter wheat flour-water suspensions, and the relationship of these factors to flour quality was investigated. Iron content of the fractions was determined colorimetrically using alpha, alpha-dipyridyl as the complexing agent. Total phorphorus was determined by a reduced molybdate colorimetric procedure. Sodium, calcium, potassium, manganese, and magnesium were determined with a Beckman D. U. Spectrophometer equipped with a flame photometry attachment.

Results of analytical, physical dough, and baking tests on the flour samples indicated that many of the samples contained abnormal protein due to environmental conditions during ripening. The coefficient of regression of loaf volume on flour protein was used as a measure of baking quality and designated gluten quality score. This score proved to be a better index of flour quality than loaf volume. Location was more important than variety in determining flour quality and mineral composition of the flour and flour fractions.

The correlation between flour ash and gluten quality score ($r=-0.569^{***}$) was comparable with that for flour protein and loaf volume ($r=+0.542^{***}$). Correlations between gluten quality score and total ash, and between gluten quality score and elemental composition of the flour fractions indicate that as the ash content of the gluten increases, the gluten quality score decreases. Each of the elements determined, except calcium, contributed in this effect.

The potassium, manganese, and calcium concentrations of the starch and potassium concentration of the water-solubles were correlated significantly and positively with gluten quality score. This suggests that the binding of these elements by the water-solubles and starch prevents them from having

a detrimental influence on gluten properties.

Phosphorus, the major component of ash (12-32%), apparently was the main element affecting gluten quality. The high correlation between the ash content of the gluten and gluten quality score (-0.818) and between phosphorus content of the gluten and gluten quality score (-0.84) suggests that either ash or phosphorus content of the gluten was more reliable than flour protein or loaf volume for predicting the breadmaking quality of flour. The phosphorus contents of water-solubles and starch also were significantly and negatively correlated with gluten quality score. This may indicate that the major portion of flour phosphorus was combined in some way with the gluten during mixing and thereby affected its physical characteristics.